CS 33

Multithreaded Programming V

Synchronizing Asynchrony

```
computation_state_t  state;
sigset_t set;
int main( ) {
  pthread_t thread;

  sigemptyset(&set);
  sigaddset(&set, SIGINT);
  pthread_sigmask(SIG_BLOCK,
    &set, 0);
  pthread_create(&thread, 0,
    monitor, 0);
  long_running_procedure( );
}
```

```
void *monitor(void *dummy) {
  int sig;
  while (1) {
    sigwait(&set, &sig);
    display(&state);
  }
  return(0);
}
```

Quiz 1

```
void long_running_procedure( )
{
  pthread_mutex_lock(&m);
  state = function(state);
  pthread_mutex_unlock(&m);
}
```

```
void display(state_t *statep)
{
  pthread_mutex_lock(&m);
  print_state(statep)
  pthread_mutex_unlock(&m);
}
```

long_running_procedure **is run by the main thread;** ***display*** **is run by the thread that is handling signals (via** ***sigwait*****). Is there a potential deadlock resulting from their use of mutexes?**

a) No, since the functions are run by separate threads

b) Yes, since ***display*** **is called in response to a signal and thus uses the same stack as does the call to** ***long_running_procedure***

Some Thread Gotchas ...

- Exit vs. pthread_exit
- Handling multiple arguments

Worker Threads

```
int main() {
  pthread_t thread[10];
  for (int i=0; i<10; i++)
    pthread_create(&thread[i], 0,
        worker, (void *)i);
  return 0;
}
```

Better Worker Threads

```
int main() {
  pthread_t thread[10];
  for (int i=0; i<10; i++)
    pthread_create(&thread[i], 0,
        worker, (void *)i);
  pthread_exit(0);
}
```

Multiple Arguments

```
void relay(int left, int right) {
  pthread_t LRthread, RLthread;

  pthread_create(&LRthread,
      0,
      copy,
      left, right);          // Can't do this ...
  pthread_create(&RLthread,
      0,
      copy,
      right, left);          // Can't do this  ...
}
```

Multiple Arguments

```
typedef struct args {
  int src;
  int dest;
} args_t;

void relay(int left, int right) {
  args_t LRargs, RLargs;
  pthread_t LRthread, RLthread;
  ...
  pthread_create(&LRthread, 0, copy, &LRargs);
  pthread_create(&RLthread, 0, copy, &RLargs);
  pthread_join(LRthread, 0);
  pthread_join(RLthread, 0);
}
```

Quiz 2

Does this work?

a) **yes**
b) **no**

Multiple Arguments

```
struct 2args {
  int src;
  int dest;
} args;

void relay(int left, int right) {
  pthread_t LRthread, RLthread;
  args.src = left; args.dest = right;
  pthread_create(&LRthread, 0, copy, &args);
  args.src = right; args.dest = left;
  pthread_create(&RLthread, 0, copy, &args);
}
```

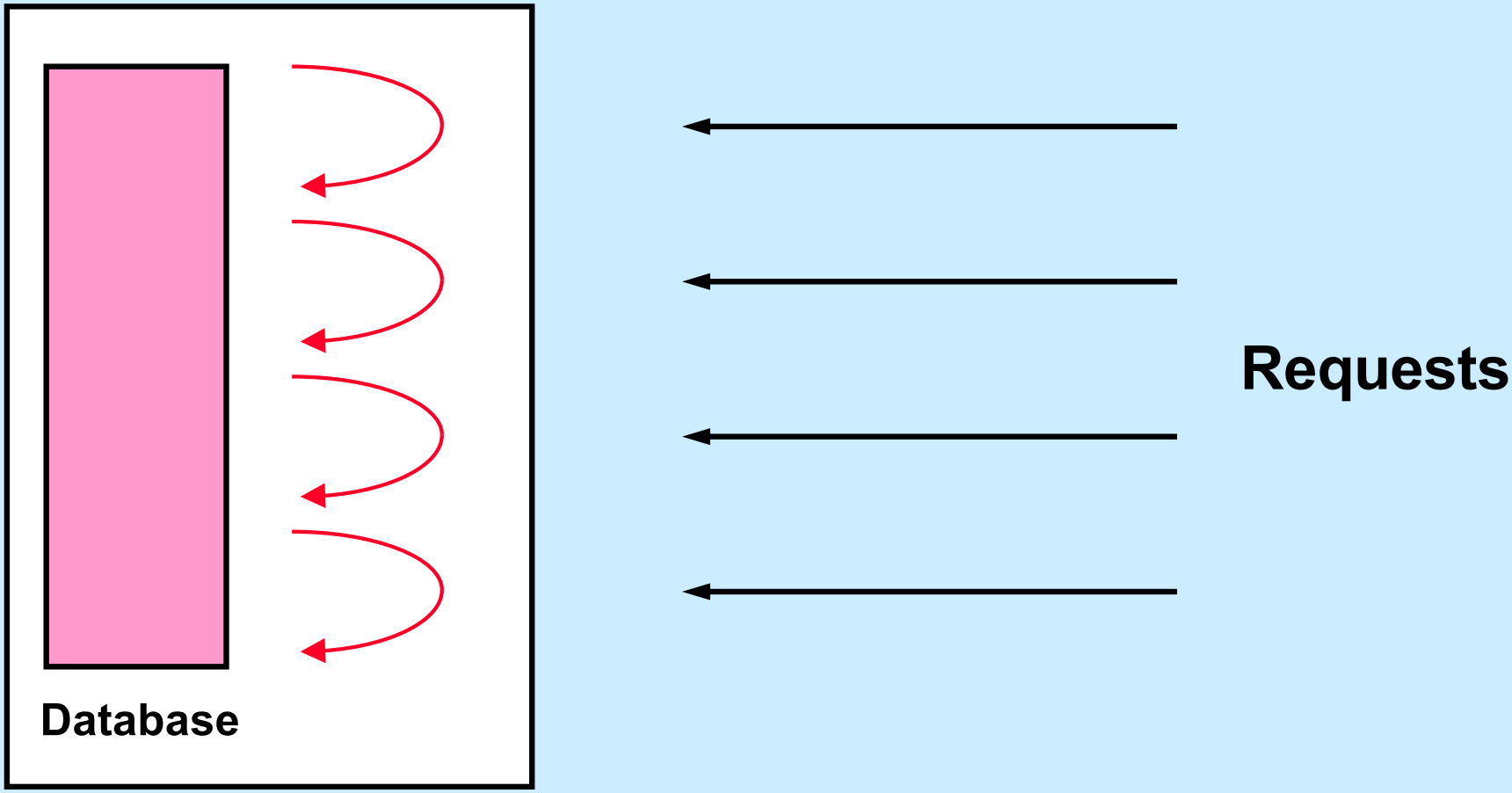
Quiz 3

Does this work?

a) **yes**
b) **no**

Cancellation

Multithreaded Database Server



Sample Code

```
void *thread_code(void *arg) {
  node_t *head = 0;
  while (1) {
    node_t *nodep;
    nodep = (node_t *)malloc(sizeof(node_t));
    nodep->next = head;
    head = nodep;
    if (read(0, &node->value,
        sizeof(node->value))
      free(nodep);
      break;
    }
  }
  return head;
}
```

```
pthread_cancel(thread);
```

Quiz 4

```
1   void *thread_code(void *arg) {
2     node_t *head = 0;
3     while (1) {
4       node_t *nodep;
5       nodep = (node_t *)malloc(size
6       nodep->next = head;
7       head = nodep;
8       if (read(0, &node->value,
            sizeof(node->value)) == 0) {
9         free(nodep);
10        break;
11      }
12    }
13    return head;
14  }
```

Where is it safe to terminate a thread within *thread_code*?

a) At all lines
b) At all lines other than 5 and 9
c) At all lines other than 8
d) At all lines other than 5, 8, and 9
e) At no lines

Cancellation Concerns

- Getting cancelled at an inopportune moment
- Cleaning up

Cancellation State

- **Pending cancel**
  - `pthread_cancel(thread)`
- **Cancels enabled or disabled**
  - `int pthread_setcancelstate(`
    `{PTHREAD_CANCEL_DISABLE`
    `PTHREAD_CANCEL_ENABLE},`
    `&oldstate)`
- **Asynchronous vs. deferred cancels**
  - `int pthread_setcanceltype(`
    `{PTHREAD_CANCEL_ASYNCHRONOUS,`
    `PTHREAD_CANCEL_DEFERRED},`
    `&oldtype)`

Sample Code – Cancellation Point

```
void *thread_code(void *arg) {
  node_t *head = 0;
  while (1) {
    node_t *nodep;
    nodep = (node_t *)malloc(sizeof(node_t));
    nodep->next = head;
    head = nodep;
    if (read(0, &node->value,
        sizeof(node->value)) == 0) {
      free(nodep);
      break;
    }
  }
  return head;
}
```

Cancellation Points

- aio_suspend
- close
- creat
- fcntl (when F_SETLCKW is the command)
- fsync
- mq_receive
- mq_send
- msync
- nanosleep
- open
- pause
- pthread_cond_wait
- pthread_cond_timedwait
- pthread_join
- pthread_testcancel
- read
- sem_wait
- sigwait
- sigwaitinfo
- sigsuspend
- sigtimedwait
- sleep
- system
- tcdrain
- wait
- waitpid
- write

Cleaning Up

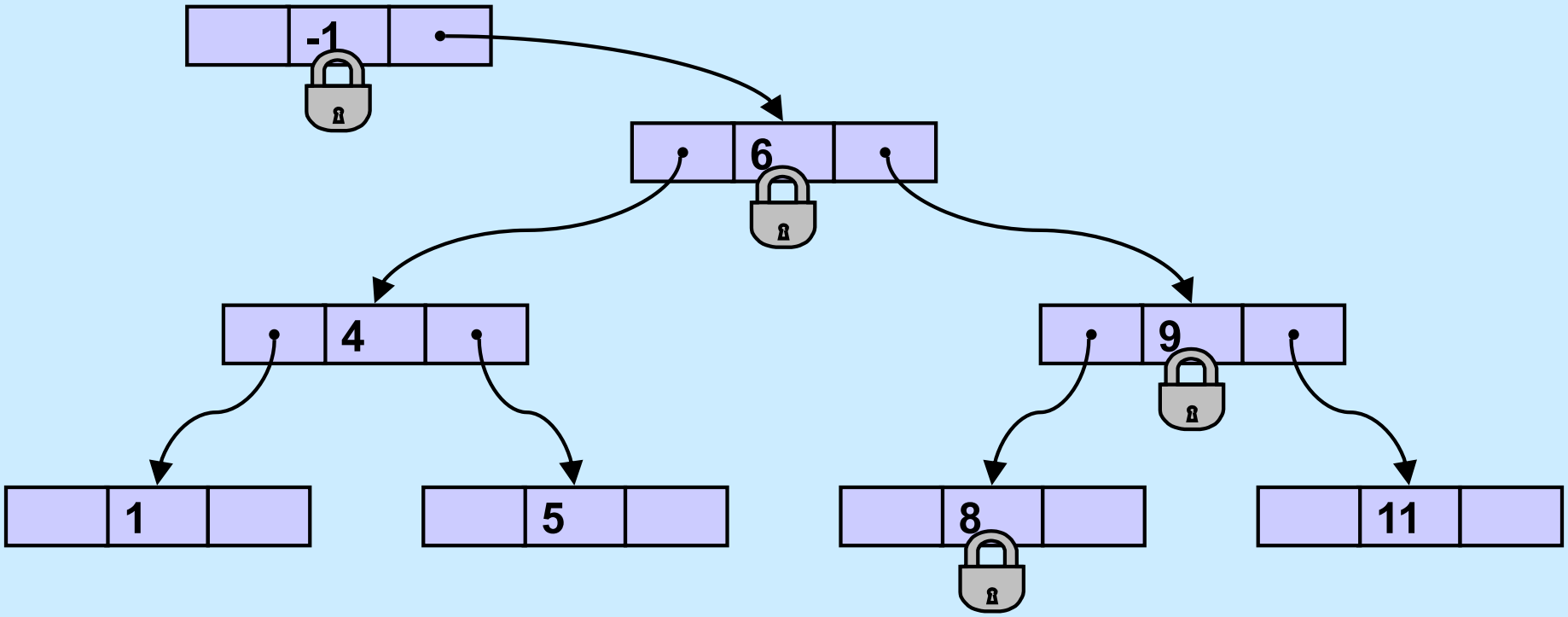
- `void pthread_cleanup_push((void)(*routine)(void *), void *arg)`
- `void pthread_cleanup_pop(int execute)`

Sample Code, Revisited

```
void *thread_code(void *arg) {
  node_t *head = 0;
  pthread_cleanup_push(
      cleanup, &head);
  while (1) {
    node_t *nodep;
    nodep = (node_t *)
       malloc(sizeof(node_t));
    nodep->next = head;
    head = nodep;
    if (read(0, &nodep->value,
        sizeof(nodep->value)) == 0) {
      free(nodep);
      break;
    }
  }
  pthread_cleanup_pop(0);
  return head;
}
```

```
void cleanup(void *arg) {
  node_t **headp = arg;
  while(*headp) {
    node_t *nodep = head->next;
    free(*headp);
    *headp = nodep;
  }
}
```

A More Complicated Situation …



Start/Stop

- **Start/Stop interface**

```
void wait_for_start(state_t *s){
  pthread_mutex_lock(&s->mutex);
  while(s->state == stopped)
    pthread_cond_wait(&s->queue, &s->mutex);
  pthread_mutex_unlock(&s->mutex);
}
void start(state_t *s) {
  pthread_mutex_lock(&s->mutex);
  s->state = started;
  pthread_cond_broadcast(&s->queue);
  pthread_mutex_unlock(&s->mutex);
}
```

Start/Stop

- **Start/Stop interface**

```
void wait_for_start(state_t *s){
  pthread_mutex_lock(&s->mutex);
  while(s->state == stopped)
    pthread_cond_wait(&s->queue,
      &s->mutex);
  pthread_mutex_unlock(&s->mutex);
}
void start(state_t *s) {
  pthread_mutex_lock(&s->mutex);
  s->state = started;
  pthread_cond_broadcast(&s->queue);
  pthread_mutex_unlock(&s->mutex);
}
```

Not a Quiz

You're in charge of designing POSIX threads. Should *pthread_cond_wait* be a cancellation point?

a) **no**
b) **yes; cancelled threads must acquire mutex before invoking cleanup handler**
c) **yes; but they don't acquire mutex**

Cancellation and Conditions

```
pthread_mutex_lock(&m);

pthread_cleanup_push(cleanup_handler, &m);

while(should_wait)
  pthread_cond_wait(&cv, &m);

read(0, buffer, len);   // read is a cancellation point

pthread_cleanup_pop(1);
```

Quiz 5

- **Start/Stop interface**

```
void wait_for_start(state_t *s){
  pthread_mutex_lock(&s->mutex);
  pthread_cleanup_push(
    cleanup_func, cleanup_arg);
  while(s->state == stopped)
    pthread_cond_wait(&s->queue, &s->mutex);
  pthread_cleanup_pop(1);
}
void start(state_t *s) {
  pthread_mutex_lock(&s->mutex);
  s->state = started;
  pthread_cond_broadcast(&s->queue);
  pthread_mutex_unlock(&s->mutex);
}
```

What should be used for *cleanup_func* and *cleanup_arg*?

a) *pthread_mutex_unlock* and *&s->mutex*

b) that and more

c) there's no need for a cleanup function

A Problem ...

- **In thread 1:**

```
if ((ret = open(path,
     O_RDWR) == -1) {
  if (errno == EINTR) {
     ...
  }
  ...
}
```

- **In thread 2:**

```
if ((ret = socket(AF_INET,
     SOCK_STREAM, 0)) {
  if (errno == ENOMEM) {
     ...
  }
  ...
}
```

There's only one errno!

However, somehow it works.

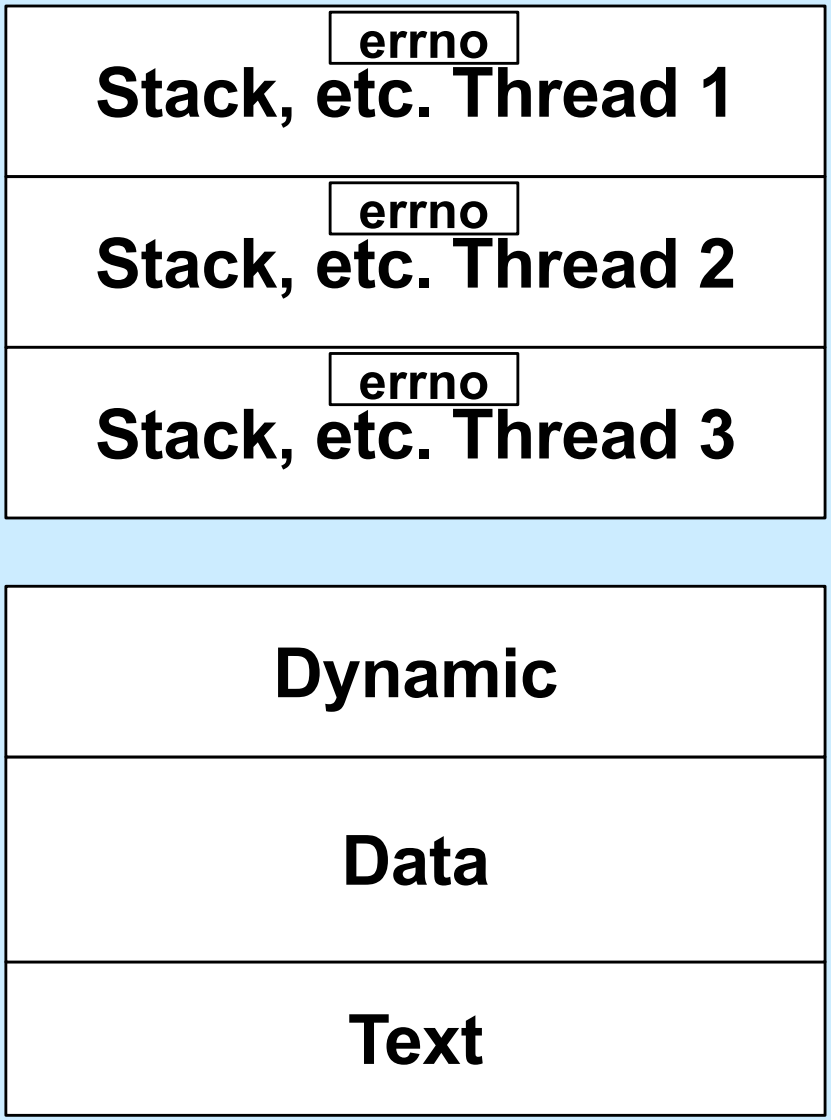
What's done???

A Solution ...

```
#define errno (*__errno_location())
```

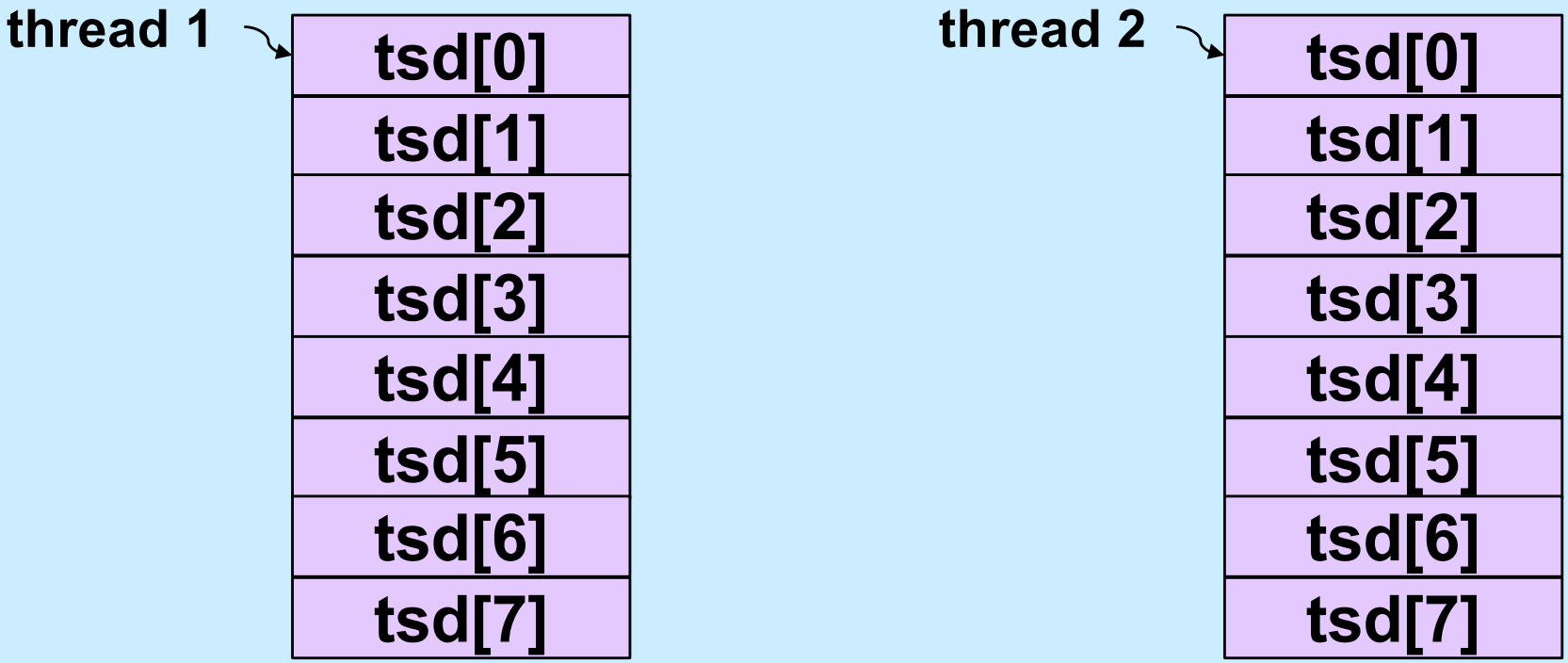
- __errno_location returns an int * that's different for each thread
  - thus each thread has, effectively, its own copy of errno

Process Address Space



Generalizing

- *Thread-specific data* (sometimes called *thread-local storage*)
  - data that's referred to by global variables, but each thread has its own private copy



Some Machinery

- `pthread_key_create(&key, cleanup_routine)`
  - **allocates a slot in the TSD arrays**
  - **provides a function to cleanup when threads terminate**
- `value = pthread_getspecific(key)`
  - **fetches from the calling thread's array**
- `pthread_setspecific(key, value)`
  - **stores into the calling thread's array**

errno (Again)

```
// executed before threads are created
pthread_key_t errno_key;
pthread_key_create(&errno_key, NULL);

// redefine errno to use thread-specific value
#define errno pthread_getspecific(errno_key);

// set current thread's errno
pthread_set_specific(errno_key, (void *)ENOMEM);
```

Beyond POSIX
TLS Extensions for ELF and gcc

- **Thread Local Storage (TLS)**

```
__thread int x=6;
  // Each thread has its own copy of x,
  // each initialized to 6.
  // Linker and compiler do the setup.
  // May be combined with static or extern.
  // Doesn't make sense for local variables!
```

Example: Per-Thread Windows

```
typedef struct {
  wcontext_t win_context;
  int file_descriptor;
} win_t;
__thread static win_t my_win;

void getWindow() {
  my_win.win_context = … ;
  my_win.file_decriptor = … ;
}

int threadWrite(char *buf) {
  int status = write_to_window(
      &my_win, buf);

  return(status);
}
```

```
void *tfunc(void * arg) {
  getWindow();

  threadWrite("started");
  …

  func2(…);
}

void func2(…) {

  threadWrite(
       "important msg");
  …
}
```

Static Local Storage and Threads

```
char *strtok(char *str, const char *delim) {
     static char *saveptr;

     ...  // find next token starting at either
      ... // str or saveptr
      ... // update saveptr

     return(&token);
}
```

Coping

- Use thread local storage
- Allocate storage internally; caller frees it
- Redesign the interface

Thread-Safe Version

```
char *strtok_r(char *str, const char *delim,
               char **saveptr) {

    ...  // find next token starting at either
     ... // str or *saveptr
     ... // update *saveptr

    return(&token);
}
```

Shared Data

- **Thread 1:**

```
printf("goto statement reached");
```

- **Thread 2:**

```
printf("Hello World\n");
```

- **Printed on display:**

```
go to Hell
```

Coping

- Wrap library calls with synchronization constructs
- Fix the libraries

Efficiency

- **Standard I/O example**
  - `getc()` **and** `putc()`
    - » **expensive and thread-safe?**
    - » **cheap and not thread-safe?**
  - **two versions**
    - » `getc()` **and** `putc()`
      - **expensive and thread-safe**
    - » `getc_unlocked()` **and** `putc_unlocked()`
      - **cheap and not thread-safe**
      - **made thread-safe with** `flockfile()` **and** `funlockfile()`

Efficiency

- **Naive**

```
for(i=0; i<lim; i++)
  putc(out[i]);
```

- **Efficient**

```
flockfile(stdout);
for(i=0; i<lim; i++)
  putc_unlocked(out[i]);
funlockfile(stdout);
```

What's Thread-Safe?

- **Everything except**

asctime()
basename()
catgets()
crypt()
ctime()
dbm_clearerr()
dbm_close()
dbm_delete()
dbm_error()
dbm_fetch()
dbm_firstkey()
dbm_nextkey()
dbm_open()
dbm_store()
dirname()
dlerror()
drand48()
ecvt()
encrypt()
endgrent()
endpwent()
endutxent()
fcvt()
ftw()
gcvt()
getc_unlocked()
getchar_unlocked()
getdate()
getenv()
getgrent()
getgrgid()
getgrnam()
gethostbyaddr()
gethostbyname()
gethostent()
getlogin()
getnetbyaddr()
getnetbyname()
getnetent()
getopt()
getprotobyname()
getprotobynumber()
getprotoent()
getpwent()
getpwnam()
getpwuid()
getservbyname()
getservbyport()
getservent()
getutxent()
getutxid()
getutxline()
gmtime()
hcreate()
hdestroy()
hsearch()
inet_ntoa()
l64a()
lgamma()
lgammaf()
lgammal()
localeconv()
localtime()
lrand48()
mrand48()
nftw()
nl_langinfo()
ptsname()
putc_unlocked()
putchar_unlocked()
putenv()
pututxline()
rand()
readdir()
setenv()
setgrent()
setkey()
setpwent()
setutxent()
strerror()
strtok()
ttyname()
unsetenv()
wcstombs()
wctomb()